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On the formation and characterization of silver nanoparticles, nanothreads and nanorods by electrical arc evaporation

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Abstract : In this communication, we report the formation and characterization of silver nanoparticles, nanothreads, and nanorods. These nano-versions were obtained by electrical arc evaporation of silver electrodes under helium ambience with varying pressures. Electrical arc evaporation was done by using ~10 V and (~50–100 amp) D.C current. The evaporated materials were deposited on cathode and formvar coated copper grid mounted on a liquid N_2 cooled specimen holder. Transmission Electron Microscopy was employed to characterize the condensed materials. These investigations revealed that the condensed materials consisted of nanoparticles and nanothreads on the grid and nanorods on the cathode. The silver nanoparticles have been found to grow under helium pressure of 50 to ~150 torr. The silver nanothreads and nanorods, on the other hand, have been formed under helium pressure of ~500 torr. Extensive electron microscopic investigations showed that the size of the nanoparticles was found to vary between ~150 nm to ~10 nm. The nanorods have diameters varying from 40 nm to 80 nm and length between 1 μm to 3 μm

Keywords : Nanoparticles, nanothreads, nanorods, arc evaporation

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1. Introduction

Nano-crystalline solids in which the grain size is in the nanometer range often have technologically interesting properties such as increased hardness and ductility. The hardness and yield stress of the materials typically increase with decreasing grain size, a phenomenon known as Hall-Petch effect [1]. In the last decades intense scientific attention has been paid to nanoparticles [2] clusters and also clusterassembled [3] crystallographic versions. This provides unique access to addressing the question of how properties change for materials forms ranging from atoms through atomic clusters/nanoparticles, to bulk. Nanoparticles display special properties different from bulk *e.g.* the quantum interference effect [4] and therefore have potential for applications. Noble metal nanoparticles, because of their surface and quantum size effects, display many noble properties [4,5] such as high catalytic activities, interesting optical and electronic properties. Accordingly, considerable effort has been focussed on the development of synthetic techniques. Many studies on the methods for their preparation were reported such as controlled chemical reduction [6,7] photochemical or radiation chemical reduction [8,9] and gas evaporation [10]. Metallic nanorods have been extensively studied because of the fundamental interest in low dimension physics and technological applications as molecular electron devices [11–14]. Most of the previous studies on metallic nanorods are focussed on the nanoscale atomic necks formed by point contacts between two metallic nodes [11–17]. In recent years long metallic nanowires with well defined structures and diameters have been fabricated by using different methods [18–20] *e.g.* stable gold nanobridge with 0.8–3 nm in thickness and 5–10 nm in length were produced by electron beam irradiation of gold (001) oriented thin films [18]. Suspended gold nanowires with 6 nm in length and diameter down to 0.6 nm were made and novel helical multishell structures are observed [19]. The Cu nanorods have been recently synthesized [20]. Previous theoretical works include melting behaviour of Pb nanowires [21] structural and vibrational properties of finite Au nanowires [22]. The purpose of this communication is to report a new synthesis route for the synthesis of silver nanorods by evaporating it in helium ambience under different pressures. The formation of nano particles and nanorods have been discerned through the technique of transmission electron microscopy.

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2. Experimental details

The evaporation of silver electrode was carried out under helium environment. The helium pressure was varied between ~50 torr and ~500 torr. Investigations of the deposited materials on the formvar cooled copper grid and on the cathode were done by the technique of electron microscopy employing imaging and diffraction mode. The apparatus used for the above synthesis consisted of vacuum chamber (vacuum upto 10^{-6} torr), fitted with electrical arc assembly, gas flow system and pressure measurement device. The electrical arc assembly consisted of two silver electrodes (positive and negative electrodes were 5 and 3 cms in length and both were 1 cm in diameter). One of the rod is sharpened for better current density. Electrical arc was triggered between the silver electrodes using out put of a dc power with voltage 10 V and current 70-80 amps. The ambience was controlled by filling helium into the chamber in the controlled manner to achieve the desired pressure between 50 and 500 torr. A mercury tube manometer was connected to the system to monitor the pressure of helium. The pulse arc evaporation was done to evaporate silver from sharp electrode. The evaporated silver was deposited on the formvar coated copper grid and on the cathode. The formvar coated copper grid was placed at a distance of ~14 cm from the electrodes. In these experiments, we tried to control the shape of Ag nanoparticles by evaporating silver under different He pressures. The deposited materials on the formvar coated copper grid and at the cathode were investigated by employing transmission electron microscopy (Philips CM-12) operating at 100 kV) employing both the imaging and diffraction modes.

3. Result and discussion

In the following we proceed to describe the electron microscopic observations and analysis made in the deposited materials on the formvar coated copper grid and on the cathode at different helium ambience.

The deposited materials on the fomvar coated copper grid at 50 to 150 torr of helium pressure consisted of nanoparticles of different sizes. The size decreases as the helium pressure is increased. The average sizes are 150 nm, 25 nm and 10 nm at 50 torr, 100 torr and 150 torr of helium pressure respectively. Figure 1(a, b, c) shows TEM micrographs of nanopaticles grown at different He pressure and Figure 1(d) shows their diffraction pattern. When the pressure in the chamber is increased still further (~500 torr) we obtained nanorods and nanothreads shown in Figure 2(a, b) and 3(a, b) respectively. Nanorods are obtained from the materials deposited on the cathode. As regards the formation of silver rods Figure 2 (a,b) it is not possible at present to put forward a clear but growth mechanism. However, it appears that the formation takes place due to continuous linear deposition of Ag on the cathode. Further investigations on this are in progress and results will be forthcoming. Nanothreads obtained from the materials deposited on formvar coated copper grid are shown in Figure 3(a,b) and their diffraction pattern in Figure 3(c). This is presumably because at these higher pressure atoms reach the substrate after suffering a multitude of collisions, energies of the deposited particles are not sufficient

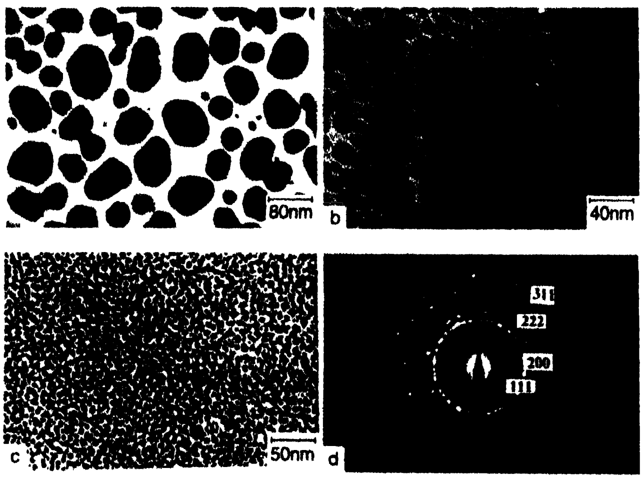


Figure 1 (a, b, c). TEM micrographs of silver nanoparticles obtained by electrical arc evaporation at 50 torr, 100 torr, 150 torr respectively. (d) Diffraction pattern of silver nanoparticles.

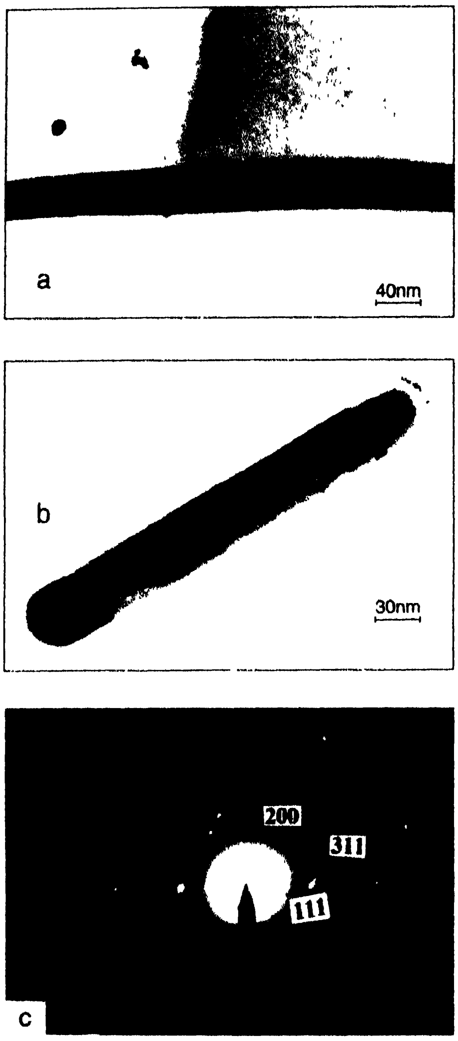
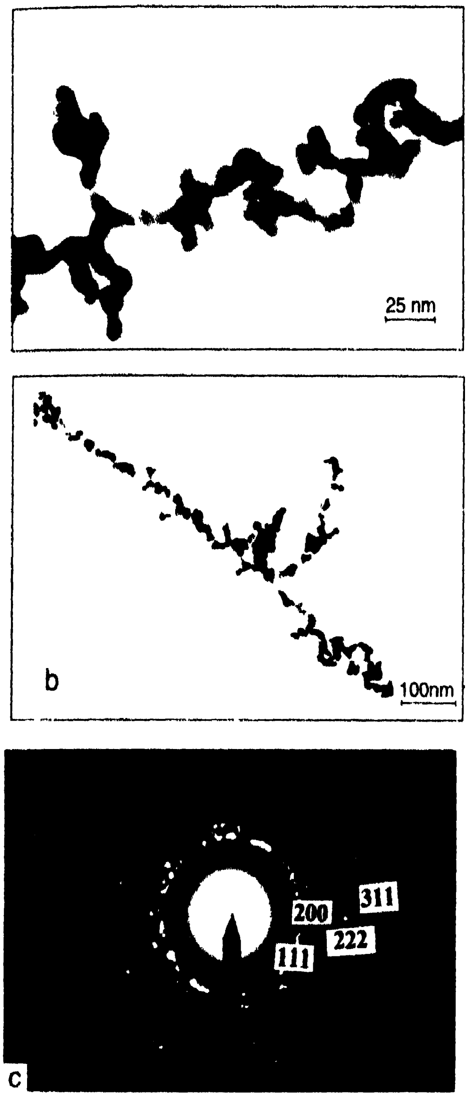


Figure 2. (a, b) TEM micrographs of silver nanorods deposited at the cathode in the electrical arc evaporation at 500 torr helium pressure. (c) Diffraction pattern of silver nanorods.

for single crystal growth but are enough for coalescence. Therefore, nanoparticles coalesce to form nanothreads.



gure 3. (a, b) TEM micrographs of silver nanothreads obtained by ctrical arc evaporation on the formvar coated copper grid at 500 torr helium pressure. (c) Diffraction pattern of silver nanothreads

Conclusion

ısed on the present investigations, the following conclusions n be drawn :

(a) Arc evaporation of silver under helium ambience (~ 50 to 500 torr) leads to the formation of nanoparticles (50 torr – ~150 torr) nanothreads and nanorods (~ 500 torr).

(b) The size of the silver nanoparticles decreases with increase in He pressure.

(c) The nanothreads are thought to get formed through coalescence of Ag nanoparticles.

(d) As regards the nanorods, it appears that the formation takes place due to continuous linear deposition of silver on the cathode.

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